The $\gamma p \to \pi^0 \eta p$ and related reactions in a chiral dynamical approach

M. Doring*, E. Oset* and D. Strottman*,†

*Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Aptd. 22085, 46071 Valencia, Spain
†Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract. Using a chiral unitary approach for meson-baryon scattering in the strangeness zero sector, where the $N^*(1535)$ and $\Delta^*(1700)$ resonances are dynamically generated, we study the reactions $\gamma p \to \pi^0 \eta p$ and $\gamma p \to \pi^0 K^0 \Sigma^+$ at photon energies at which the final states are produced close to threshold. Among several reaction mechanisms, we find the most important is the excitation of the $\Delta^*(1700)$ state which subsequently decays into a pseudoscalar meson and the $N^*(1535)$. Hence, the reaction provides useful information with which to test current theories of the dynamical generation of the low-lying $1/2^-$ and $3/2^-$ states. Predictions are made for cross sections and invariant mass distributions which can be compared with forthcoming experiments at ELSA.

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The $\gamma p \to \pi\pi N$ reaction has had a deep impact in hadronic physics in the last years [1]. The $SU(3)$ extension of the reaction promises as well to teach us interesting physics. With this aim in mind, we have tackled the study of the analogous reaction $\gamma p \to \pi^0 \eta p$ where the ηp final state can form the $N^*(1535)$ resonance. Besides processes relevant in $\gamma p \to \pi\pi N$ [2], we also include [3] the contribution from the $\Delta^*(1700)$ resonance which qualifies as dynamically generated through the interaction of the 0^- meson octet and the $3/2^+$ baryon decuplet as recent studies show [4, 5].

At the same time we also study the $\gamma p \to \pi^0 K^0 \Sigma^+$ reaction and make predictions for its cross section, taking advantage of the fact that it appears naturally within the coupled channels formalism of the $\gamma p \to \pi^0 \eta p$ reaction and leads to a further test of consistency of the ideas explored here. Both reactions are currently being analyzed at ELSA[6].

In Fig. 1 some photoproduction mechanisms are shown. In all diagrams, the gray blob signifies the dynamically generated $N^*(1535)$ that provides the final state interaction (meson-baryon $\to \eta p$) [7, 3]. Diagram (c) shows the pole term that accompanies the contact term (b) in order to ensure gauge invariance; for a more detailed discussion see Ref. [3]. Similar terms are included for diagrams (a), (d), and (f) but not separately drawn.

In Fig. 1 one finds also the contributions from explicit resonances, where in (e) and (f) the X^* means $\Delta(1232)$, $N^*(1520)$, or $\Sigma^*(1385)$. There, m stands for mesons (π, η, K). The $\Delta^* \equiv \Delta^*(1700)$ in Fig. 1 is in the present picture a dynamically generated $3/2^-$ resonance from Ref. [5] with predicted couplings to ηp and $K\Sigma^*$. From these couplings, also the tree level diagram in Fig. 1 originates for the photoproduction which gives the largest contribution.

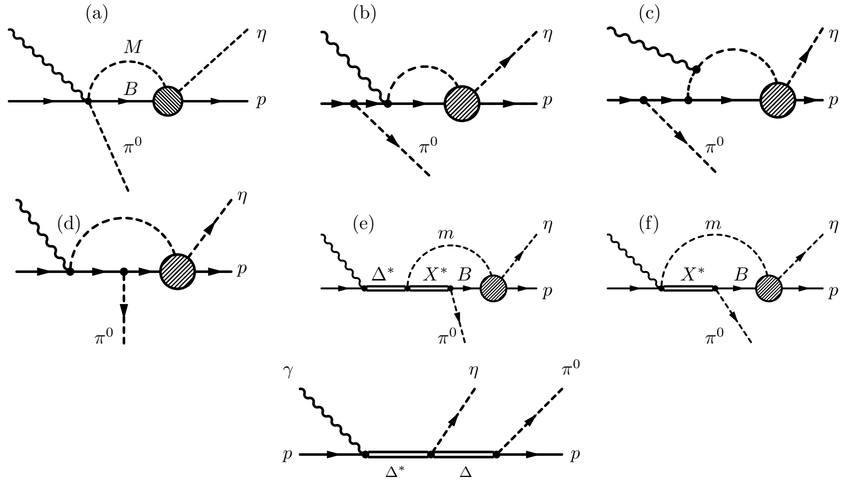

FIGURE 1. Photoproduction mechanisms for the $\pi^0\eta p$ final state.

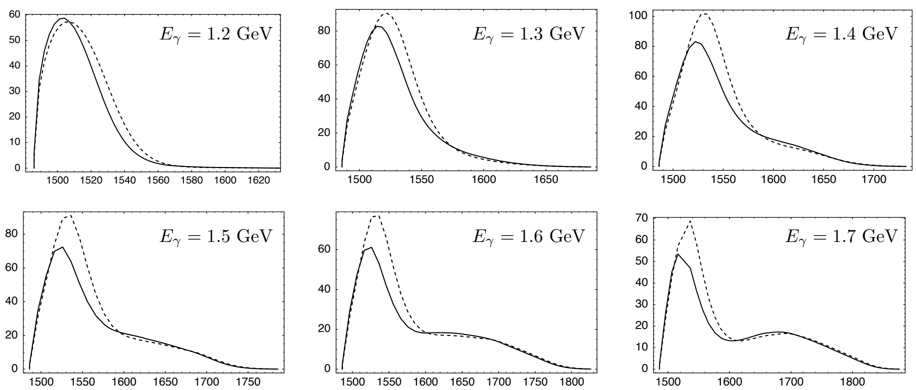

FIGURE 2. Invariant mass spectrum $\frac{d\sigma}{dM_I(\eta p)}$ [μb GeV^{-1}] as a function of $M_I(\eta p)$ [MeV] for various photon lab energies E_γ. Solid and dashed lines: Full and reduced model for the $N^*(1535)$, respectively.

There are no free parameters in the theory once the low energy constants of the $N^*(1535)$ are fitted in the $\pi N \to \pi N$ reaction [7] and the regularization of the first loop of the processes in Fig. 1 in the $\gamma p \to \eta p$ reaction [3] .

The invariant mass spectra for $M_I(\eta p)$ and $M_I(\pi^0 p)$ and cross section for the $\gamma p \to \pi^0\eta p$ reaction are predicted which can be directly compared to the forthcoming experiments at the ELSA facility. In Fig. 2 the spectrum for $M_I(\eta p)$ is shown for several lab photon energies E_γ . The solid and dashed curves correspond to the full and simplified model for the $N^*(1535)$ resonance , see Ref. [7], [3], and we take the difference as a hint for the theoretical error although at higher energies it could be larger. The $N^*(1535)$ is clearly visible in the spectrum. At higher E_γ, we observe a second peak which moves with the energy. This is a reflection of the $\Delta(1232)$ in the tree level process which is on shell around these invariant masses. For a more detailed discussion, see Ref. [3]. The total cross section is plotted in Fig. 3. From the processes with $N^*(1535)$, diagram (e) from Fig. 1 with $m = \eta$, $X^* = \Delta(1232)$ gives the largest contribution which is due to the

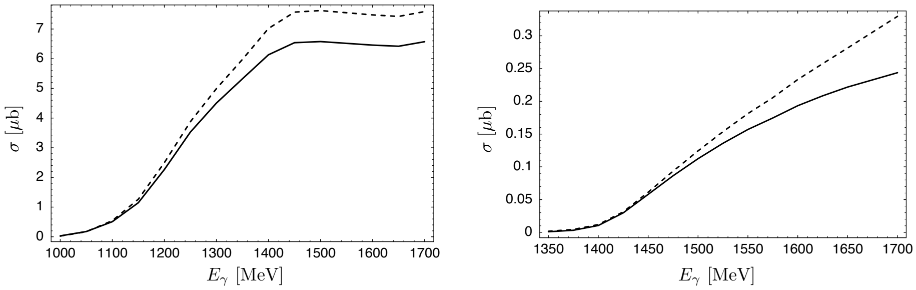

FIGURE 3. Left side: Integrated cross section σ for the $\gamma p \to \pi^0 \eta p$ reaction. Right side: σ for the $\gamma p \to \pi^0 K^0 \Sigma^+$ reaction . Solid line: Full model for the $N^*(1535)$. Dashed line: Reduced model.

strong $\eta p \to \eta p$ transition in the model for the $N^*(1535)$. Also, the tree level diagram strongly contributes.

The cross section for the second reaction, $\gamma p \to \pi^0 K^0 \Sigma^+$, which is calculated in the same framework is much smaller than for the $\pi^0 \eta p$ final state as Fig. 3 shows.

In this paper we have studied the reactions $\gamma p \to \pi^0 \eta p$ and $\gamma p \to \pi^0 K^0 \Sigma^+$ within a chiral unitary framework which considers the interaction of mesons and baryons in coupled channels and dynamically generates the $N^*(1535)$. From the various processes, we find dominant the decay of the dynamically generated $\Delta^*(1700)$ resonance into $\eta\Delta$, followed by the unitarization, or in other words, the $\Delta^*(1700) \to \pi^0 N^*(1535)$ decay. A similar term provides also a tree level process which leads, together with the $N^*(1535)$, to a characteristic double hump structure in the ηp and $\pi^0 p$ invariant masses at higher photon energies.

Although we have used the $\Delta^*(1700)$ explicitly in the model, its couplings are taken from the chiral theory where it appears dynamically generated and the experiment would be indirectly testing such couplings.

The measurement of both cross sections is being performed at the ELSA/Bonn Laboratory and hence the predictions are both interesting and opportune and can help us gain a better insight in the nature of some resonances, particularly the $N^*(1535)$ and the $\Delta^*(1700)$ in the present case.

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